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FOR

MICROELECTROMECHANICAL SWITCH WITH AN ARC REDUCTION ENVIRONMENT

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FIELD

[0001] Disclosed embodiments of the present invention relate to the field of microelectromechanical systems (MEMS), and in particular to MEMS switches with an arc reduction environment.

BACKGROUND

[0002] A microelectromechanical system (MEMS) is a microdevice that integrates mechanical and electrical elements on a common substrate using microfabrication technology. The electrical elements are typically formed using integrated circuit fabrication techniques, while the mechanical elements are typically fabricated using lithographic techniques that selectively micromachine portions of the substrate. Additional layers are often added to the substrate and then micromachined until the MEMS device is in a desired configuration. MEMS devices include actuators, sensors, switches, accelerometers, and modulators.

[0003] One type of MEMS switch includes a suspended connecting member, or beam, that is electrostatically deflected by energizing an actuation electrode. The deflected beam includes one or more protuberances that engage one or more electrical contacts to establish one or more electrical connections between isolated contacts. A beam anchored at one end while suspended over a contact at the other end is often called a cantilevered beam. A beam anchored at opposite ends and suspended over one or more electrical contacts is often called a bridge beam. A cap is often placed over the switch components to isolate them from unwanted foreign materials.

[0004] One issue that arises with current MEMS switches is that when the switch is operated at high power there is a tendency for an environment immediately surrounding the switch to become conductive, leading to the formation of an arc between the protuberance and the signal contact. This arc may raise the temperature of the protuberance and the signal contact to a point where the materials melt. Thus,

when the switch is activated the protuberance and the signal will contact each other and weld together, thereby decreasing the life of the switch.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

[0006] **Figure 1** illustrates a side view of a microelectromechanical system (MEMS) switch with an arc reduction environment, in accordance with an embodiment of the present invention;

[0007] **Figure 2** illustrates a side view of the MEMS switch with the beam deflected towards a pair of actuation electrodes, in accordance with an embodiment of the present invention;

[0008] **Figure 3** illustrates a top view of the MEMS switch with a signal voltage flowing through signal lines, in accordance with an embodiment of the present invention;

[0009] **Figure 4** illustrates a flow chart of the MEMS switch operating with a hydride coating, in accordance with an embodiment of the present invention;

[0010] **Figures 5a-5d** illustrate several coating schemes in accordance with various embodiments of the present invention;

[0011] **Figure 6** illustrates the coating being placed as a dimple on the beam of the MEMS switch, in accordance with an embodiment of the present invention; and

[0012] **Figure 7** illustrates a block diagram of an electronic system incorporating at least one MEMS switch, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0013] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, wherein like numerals designate like parts throughout, and in which is shown, by way of illustration, specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the embodiments of the present invention. Therefore, the following detailed description is not to be taken in a limiting sense and the scope of the embodiments of the present invention is defined by the appended claims and their equivalents.

[0014] Various operations will be described as multiple discrete operations in turn, in a manner that is most helpful in understanding the embodiments; however, the order of description should not be construed to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

[0015] The phrase "in one embodiment" is used repeatedly. The phrase generally does not refer to the same embodiment, however, it may. The terms "comprising," "having," and including" are synonymous, unless the context dictates otherwise.

[0016] **Figure 1** illustrates a microelectromechanical system (MEMS) switch **100** with an arc reduction environment **104**, in accordance with an embodiment of this invention. The MEMS switch **100** includes a substrate **108** with an upper surface **111**. The substrate **108** may be part of a chip or any other electronic device. The substrate **108** may be a nonconductive material that holds other components including, but not limited to, anchors **112**, actuation electrodes **114** and **116**, signal contact **120**, and a cap **124**. The actuation electrodes **114** and **116** and the signal contact **120** may be electrically coupled to other electronic components via conducting traces in the substrate **108** (not shown), or through other means. The actuation electrodes **114** and **116** and the signal contact **120** may be coupled to different voltage power sources. The cap **124** may be made of an insulating material and may define a portion of the

boundaries of the environment **104**. The environment **104** may be largely free of foreign materials and debris, and may imitate some of the characteristics of a vacuum. A coating **146** may be placed at some point in the environment **104** to at least facilitate the existence of an arc reduction environment, to be discussed further below.

[0017] In one embodiment, the switch **100** may further include a bridge beam **128** having a flexible portion supported at both ends by the anchors **112**. It should be noted that in alternative embodiments, the beam **128** may be suspended over the signal contact **120** in a cantilevered fashion. The beam **128** may be suspended such that there is a gap between the actuation electrodes **114** and **116** and the beam **128**. The gap may be sized so that the actuation electrodes **114** and **116** are in electrostatic communication with corresponding portions of the beams called beam electrodes. The actuation electrodes **114** and **116** and the corresponding beam electrodes may be referred to as actuation electrode pairs **134** and **136**. The beam **128** may also be suspended such that there is a gap in between the signal contact **120** and another beam electrode. The signal contact **120** and the corresponding beam electrode may be referred to as the signal electrode pair **135**. In this embodiment, the coating **146** may be located at some point between at least one of the electrode pairs **134**, **135**, and **136**. However, other embodiments may include the coating placed in other locations, e.g., on the inside surface of the cap **124**.

[0018] In one embodiment, the MEMS switch **100** may be in an "on" state when an actuating voltage is applied to the actuation electrodes **114** and **116**. In one embodiment the actuating voltage may be a direct current (DC) voltage. The actuating voltage may create an attractive electrostatic force between the actuation electrodes **114** and **116** and the beam **128** that deflects the beam **128** downward. See **Figure 2**. The beam **128** may move toward the actuation electrodes **114** and **116** until a protuberance **132** electrically couples the beam **128** with the signal contact **120**. The protuberance **132** may be a conductive protrusion on the beam electrode corresponding to the signal contact **120**. In one embodiment the protuberance **132** may prevent the beam **128** from coming in contact with the actuation electrodes **114** and **116** when the switch is in an "on" position, thereby avoiding a short circuit. In various embodiments,

the beam **128** may electrically couple the signal contact **120** without the protuberance **132**.

[0019] In one embodiment, the beam **128** may be made of a purely conductive material. In another embodiment the beam **128** may be made of an insulative material coated with a conductive material. The beam **128** may be resilient enough to withstand continuous bending and unbending during activation of the MEMS switch **100**, for a target operational life of the switch **100**.

[0020] **Figure 3** illustrates a top view of the MEMS switch **100**, in accordance with an embodiment of this invention. When the actuating voltage is applied to the actuation electrodes **114** and **116**, the beam **128** may electrically couple together a pair of signal lines **148a** and **148b** through an input signal contact **120a** and an output signal contact **120b**, such that a signal voltage **150** may be transmitted. In one embodiment the signal voltage **150** may be a radio frequency (RF) electrical signal.

[0021] In another embodiment, the signal lines **148*** (where asterisk may be "a" or "b") may be electrically coupled to one another such that the beam **128** acts as a shunt when it engages the signal contacts **120***.

[0022] In various embodiments the number and orientation of the signal lines **148*** (along with the respective signal contacts **120***), the actuation electrodes **114** and **116**, and the protuberances may change without departing from the scope of embodiments of this invention. For example, one embodiment could embed one or more actuation electrodes into the substrate **108**, while keeping the signal lines **148*** on the surface.

[0023] A prior art environment may contain a number of primary electrons in between the electrodes. An electric field created between the electrodes may cause the primary electrons to collide with, and dislodge secondary electrons from, the uncoated electrodes. As more and more electrons are dislodged from the electrodes into the environment, the environment may become more conducive to an arc because of the increased concentration of electrons between the electrodes. An arc would further exacerbate the situation by increasing the number of collisions of the primary electrons with the electrodes, thereby releasing more secondary electrons. This type of reaction

may sometimes be referred to as multipaction. Arcing due to multipactoring may be one of the factors limiting the power capacities of present MEMS switches.

[0024] To at least facilitate the reduction of multipactoring, one embodiment of the present invention employs a coating **146** having a coefficient of secondary electron emission lower than the electrode over which it is placed. The coating **146** may be more resistant to this secondary electron emission than the underlying electrode, which may result in the environment being less conducive to arcing between the beam **128** and the signal contact **120** because of a lower concentration of electrons in the environment **104**. Said another way, placing a coating **146** having a relatively low coefficient of secondary electron emission over at least one electrode may at least facilitate the existence of an arc reduction environment by suppressing the charge multiplication within the environment. In one embodiment, this coating may include, e.g., titanium or a titanium nitride. However, other coating materials having relatively low coefficients of secondary electron emission may be additionally or alternatively employed in various embodiments.

[0025] In one embodiment, placing a layer of the coating **146** over the electrode may allow the electrode to be constructed of other materials, better suited for other design constraints. For example, in one embodiment the beam may be constructed of a resilient material, e.g., gold, in order to withstand the repetitive bending from the MEMS switch **100** being turned on and off. Placing a layer of the coating **146**, e.g., titanium, over this resilient material, may at least facilitate the existence of an arc reduction environment without sacrificing the resiliency of the beam **128**.

[0026] In one embodiment, the coating **146** may be comprised of a hydride material, which may at least facilitate the existence of an arc reduction environment by increasing the pressure within the cap **124**. A hydride material may be a compound in which hydrogen is bonded chemically to a metal, metalloid, or alloy. This bonding may be reversible such that the hydrogen stored in the compound may be desorbed into the environment under certain atmospheric conditions, e.g., temperature and pressure.

[0027] **Figure 4** illustrates a flowchart of the MEMS switch **100** operating with a hydride coating, in accordance with an embodiment of this invention. The hydride

coating may become heated due to current flowing through the signal electrode pair and/or arcing between any of the electrode pairs **200**. The heated hydride coating may release hydrogen into the environment **204**. The released hydrogen may increase the pressure of the environment **208**. This high-pressure environment may either extinguish an existing arc or prevent an arc from forming, thereby at least facilitating the existence of an arc reduction environment **212**.

[0028] The amount and type of hydride material to be applied as a coating may be selected based, at least in part, on the material's absorption and desorption rates occurring at particular atmospheric conditions. Additional factors to be considered may include, but are not limited to, the pressure needed for an effective arc reduction environment, the area of the environment, the placement of the coating, the actuating and signal voltage levels, the types of conductors used in the electrodes, and the concentration of primary electrons in the environment. Examples of hydrides may include, but are not limited to, a nickel hydride, a magnesium hydride, an iron hydride, a palladium hydride, and a titanium hydride.

[0029] In various embodiments, the coating **146** may be a hydride that also has a relatively low coefficient of secondary electron emission. Various embodiments may also include a hydride placed on certain surfaces and a coating with a relatively low coefficient of electron emission placed on other surfaces.

[0030] **Figure 5** illustrates several coating schemes in accordance with various embodiments of the present invention. **Fig. 5a** illustrates the coating **146** being disposed between the electrodes of only one of the electrode pairs. Specifically, the coating **146** is applied to the beam electrode of the first actuation electrode pair **134**. In various embodiments, either of the other two electrode pairs **135** or **136** may have the coating **146**. In various embodiments, the coating **134** may be applied to either or both of the electrodes of the electrode pair **134**. For example, various embodiments could include the coating **146** being applied to the actuation electrode **114** only or applied to both the beam electrode and the actuation electrode **114**.

[0031] **Figure 5b** illustrates the coating **146** being disposed between the electrodes of two electrode pairs **134** and **135**, in accordance with an embodiment of

this invention. **Fig. 5b** illustrates one electrode of each electrode pair **134** and **135** being coated with the coating **146**. Specifically, the beam electrode is coated in the first actuation electrode pair **134** and the signal contact **120** is coated in the signal electrode pair **135**. However, in various embodiments, either or both of the electrodes of the electrode pairs **134** and **135** may be coated with the coating **146**. Additionally, in one embodiment, the other actuation electrode pair may have a coating disposed between its electrodes.

[0032] **Figure 5c** illustrates an embodiment having the coating **146** disposed between each of the electrode pairs **134**, **135**, and **136**. Specifically, the coating **146** is applied to the actuation electrodes **114** and **116** and the signal contact **120**. In various embodiments, the beam electrodes may be additionally or alternatively coated in each of the electrode pairs **134**, **135**, and **136**. Various embodiments may include a different number of electrode pairs with the coating scheme being adjusted to accommodate the design considerations of the particular embodiment.

[0033] **Figure 5d** illustrates the coating **146** being applied to the inside surface of the cap **124**, in accordance with one embodiment of the invention. Applying the coating **146** to the cap **124** may facilitate the application and allow for the coating step to be done at a number of different times in the process. The coating schemes illustrated in the embodiments of **Figure 5** represent only some of the many possible coating schemes available to embodiments of the present invention, other coating schemes may be used in other embodiments.

[0034] **Figure 6** illustrates an embodiment of the present invention wherein the coating **146** is placed as a dimple on the portion of the beam **128** corresponding to the signal contact **120**. In this embodiment, the coating **146** may serve similar functions as the protuberance **132** discussed with reference to above embodiments.

[0035] **Figure 7** illustrates a block diagram of an electronic system **300** of one embodiment incorporating at least one MEMS switch **302**, similar to MEMS switch **100** illustrated in **Figures 1-6**. The MEMS switch **302** may form a part of a circuit **304** that is coupled to a bus **308**. In one embodiment, the circuit **304** may include a processor **312**, which can be of any type. As used herein, processor means any type of circuit such as,

but not limited to, a microprocessor, a graphics processor, and a digital signal processor.

[0036] Other types of circuits that can be included in the circuit **304** are a custom circuit or an application-specific integrated circuit, such as communications circuit **314** for use in wireless devices.

[0037] The electronic system **300** may also include a main memory **316**, a graphics processor **320**, a mass storage device **324**, and an input/output module **328** coupled to each other by way of the bus **308**, as shown. Examples of the memory **316** include, but are not limited to, static random access memory (SRAM) and dynamic random access memory (DRAM). Examples of the mass storage device **324** include, but are not limited to, a hard disk drive, a compact disk drive (CD), a digital versatile disk drive (DVD), and so forth. Examples of the input/output module **328** include, but are not limited to, a keyboard, a cursor control device, a display, a network interface, and so forth. Examples of the bus **308** include, but are not limited to, a peripheral control interface (PCI) bus, and an industry standard architecture (ISA) bus, and so forth. In various embodiments, the system **300** may be a wireless mobile phone, a personal digital assistant, a network router, a tester, a sensor, and a server.

[0038] MEMS switch **302** can be implemented in a number of different forms, including an electronic package, an electronic system, a computer system, one or more methods of fabricating an electronic package, and one or more methods of fabricating a circuit that includes the package.

[0039] Although specific embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiment shown and described without departing from the scope of the present invention. For example, while the above embodiments describe a MEMS switch, the invention is not so limited, and may be practiced at other scales, e.g., nanoscale. Those with skill in the art will readily appreciate that the present invention may be implemented in a very wide variety of embodiments. This application is

intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments of this invention be limited only by the claims and the equivalents thereof.